CORROSION FATIGUE OF AL-ALLOY AA7020
IN DIFFERENT SURFACE TREATMENT STATES

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ABSTRACT

The consequences of near surface materials properties due to distinct manufacturing operations on damage evolution during corrosion fatigue of the Al-base alloy AA7020 (German grade AlZn4.5Mg1) were systematically investigated. Specimens with distinct shot peening treatments were investigated in comparison with turned or polished states. Surface topography as well as near surface work hardening states and residual stress distributions were taken into account. Bending fatigue tests under salt spray test conditions were carried out and crack formation as well as crack propagation were studied in comparison with fatigue tests in laboratory air. It could be shown, that mechanical surface treatments, which have beneficial effects in dry air are also advantageous under corrosion fatigue conditions. Characteristic results are presented and discussed taking the stability of near surface materials properties during fatigue into account.

KEY WORDS

Corrosion fatigue, aluminium alloys, shot peening, salt spray test, residual stress

INTRODUCTION

The beneficial effects of shot peening treatments on the fatigue behavior of components are well known and documented in literature [1, 2]. The aim of this work was to investigate in how far these effects are also active in the case of corrosion fatigue. To clarify this question, bending fatigue tests in a corrosive environment were carried out at specimens made of AA7020. Specimens were loaded in salt spray fog, produced of water with 5% NaCl similar to sea water. As a reference, additional tests were carried out under laboratory air conditions.

METHODS OF INVESTIGATIONS AND EXPERIMENTAL DETAILS

Flat bending fatigue specimens with the geometry shown in Fig. 1 of AA7020 (German grade AlZn4.5Mg1) were manufactured in rolling direction from rolled sheets with the chemical composition 4.76 Zn, 1.26 Mg, 0.23 Si, 0.17 Cu, 0.24 Mn, 0.206 Cr, 0.32 Fe, rest Al (wt-%). There was no further machining of the rolled surfaces. Specimens were heat treated after manufacturing starting with solution annealing at 490 °C for 30 min. Then, after quenching in water of room temperature, a two stage hardening process took place with 8 h at 100 °C and additionally 20 h at 150 °C. The mechanical properties were: $R_{p0.2}$ = 301 MPa, UTS = 350 MPa, Young’s modulus = 71 GPa, fracture strain: 11%. Shot peening with a covering rate of 200% and an Almen intensity of 8A“ was carried out using ceramic shots (Ø 0.6 mm) in order to avoid contact corrosion damage. Bending fatigue tests were performed on flat bending testing machines (R = -1) at a frequency of 25 Hz both under laboratory air conditions as well as under salt spray fog.

The corrosive environment was produced using a specially designed experimental set-up. A salt spray fog was produced from saturated steam of a 5% NaCl-solution. Woehler curves both under corrosive conditions and under laboratory air were produced applying five different stress amplitudes using five specimens on each load level. The diagrams always show failure probabilities of 50%, which were calculated using the $\arcsin\sqrt{P}$-method.

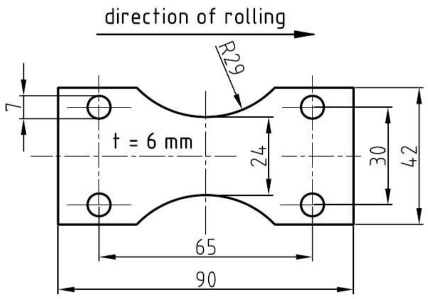

Figure 1: Geometry of specimen for bending tests

Surface topographies of the specimens were analysed using a laser optical tracing stylus instrument. The topography was scanned in an area of 2 x 2 mm^2 using 500 measuring points per mm.

Residual Stresses were determined by X-ray diffraction technique, using the interference of Cuka-radiation at the {333} and {511} lattice planes, at a glancing angle of $2Q = 162.487°$. For stress evaluation, the $\sin^2 y$-method was applied and the elastic constant $½s_2 = 1.865*10^{-5}$ mm^2/N was used. Residual stress depth profiles were determined without correction of stress relief by successive electrochemical materials removal. To estimate micro residual stresses, caused by work hardening, integral width (IW) values of X-ray interference lines were determined.

RESULTS AND DISCUSSION

Fig. 2 shows the surface topographies of specimens in rolled, shot peened and electrolytically polished conditions. Polished specimens have the smoothest surface, however due to the electrochemical process, sporadically grooves are observed. Shot peened specimens have highest roughness values. Measured R_a- and R_z-values are summarized in Tab. 1.

Residual stress states at the surface of the specimens were statistically evaluated. Results are summarized in Fig. 3 and Tab. 2. One can clearly see three classes of residual stress states: Shot peened specimens, as expected, show high surface compressive residual stresses whereas heat treated and polished states have only negligible residual stresses at the surface. Fig. 4 shows depth distributions of heat treated and of shot peened specimens measured along and across the rolling direction. As already shown in Fig. 3, heat treated specimens are nearly residual stress free. Due to the texture and the microstructure of the material in this condition, measurements were possible only up to a distance of 0.15 mm from the surface. Shot peened specimens have typical depth distributions of compressive residual stresses up to a distance of approximately 0.25 mm from the surface with amounts of -250 MPa immediately at the surface and maximum values between -350 MPa and -400 MPa below the surface.

In Fig. 5, the corresponding IW-depth distributions are shown. As expected, shot peened states have in contrast to heat treated specimens, a work hardened surface layer with increased IW-values. However, data show a considerable scattering and consequently, thickness of the affected surface layer is difficult to determine.

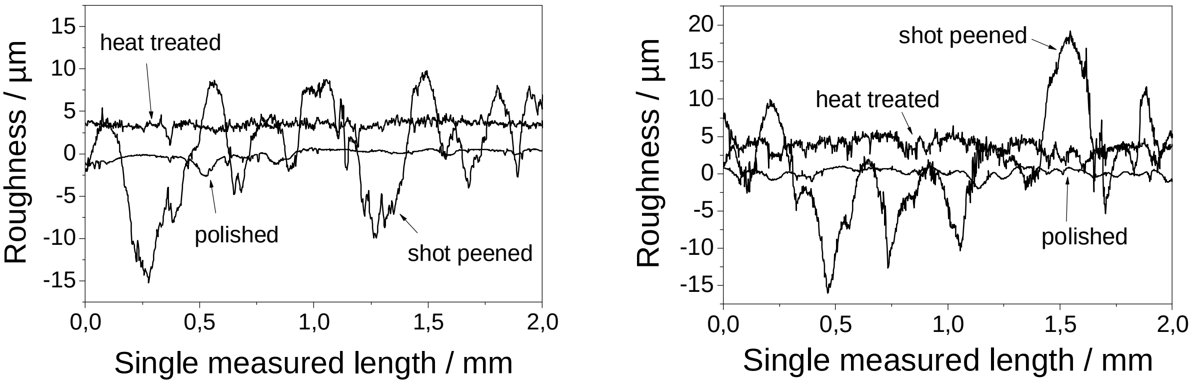

Figure 2: Roughness of surface along (left) and across (right) to rolling of direction

Condition	**Along to rolling direction**		**Across to rolling direction**	
	R_a / µm	**R_z / µm**	**R_a / µm**	**R_z / µm**
Heat treated	0,31	2,00	0,59	4,12
Polished	0,23	1,41	0,29	1,66
Shot peened	2,55	11,13	2,94	12,86

Table 1: Comparison of roughness values

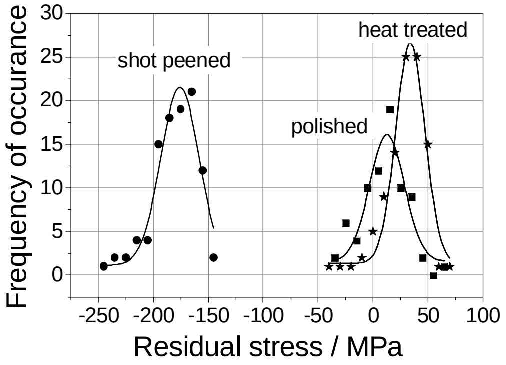

Figure 3: Gaussian distribution of residual the stress at the surface

Condition	**Mean value**	**Range**	**Quantity of specimens**
Heat treated	+ 34 MPa	⌖26 MPa	100
Polished	+ 13 MPa	⌖32 MPa	70
Shot peened	- 176 MPa	⌖35 MPa	100

Table 2: Mean values and ranges of residual stresses

Fig. 6 shows S/N-curves of the different materials states in laboratory air (left) and under corrosive conditions (right). Heat treated and additionally polished specimens have identical lifetimes and fatigue strengths resp. under laboratory conditions whereas shot peened conditions show considerably higher strength. For a bending stress amplitude of 200 MPa, 9 x 10^4 cycles to failure can be reached in the heat treated state and shot peening increases lifetime to 2 x 10^5 in spite of the higher roughness of the specimens. The fact that smoothing the surface by electrolytic polishing does not have remarkable effect on fatigue life may be attributed, as mentioned above, to single grooves acting as crack starters due to their notch effect.

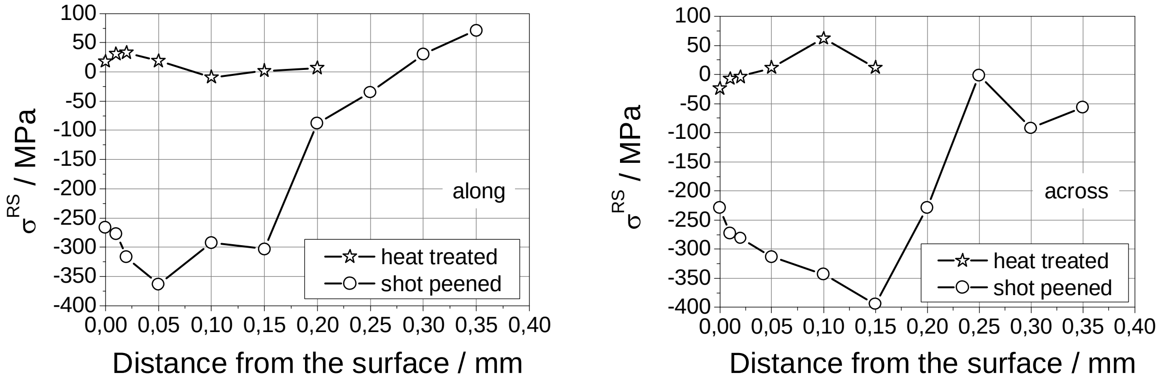

Figure 4: Residual stress depth distribution along (left) and across (right) to rolling direction

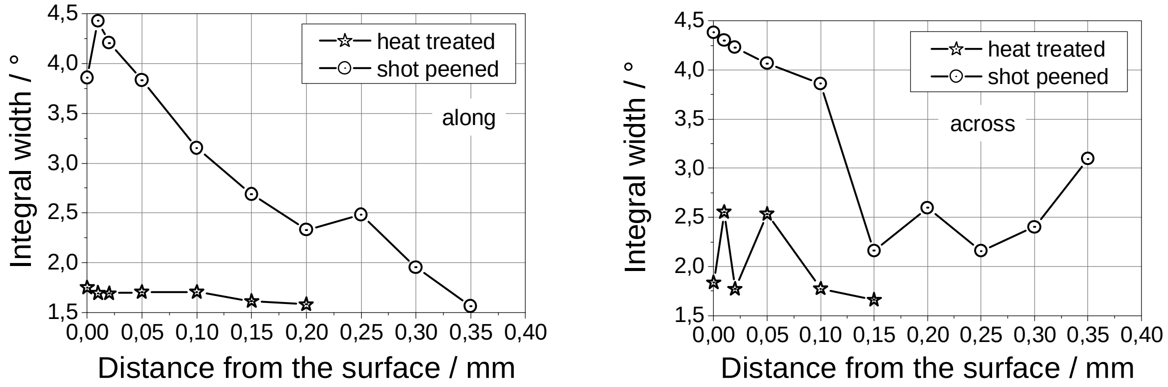

Figure 5: Depth distribution of integral width along (left) and across (right) to rolling direction

Under corrosive conditions, heat treated and additionally electrolytically polished specimens have different S/N-curves and the first ones have longer fatigue lifes. This is due to the fact that electrolytic polishing may be looked upon as a corrosion process producing some premature damage before starting the fatigue test. As in the case of laboratory atmosphere shot peening considerably increases fatigue life and strength resp. but there is no parallel shift of the S/N-curve as it is the case under laboratory air. Lifetime increase compared to the untreated states by shot peening is clearly the more expressed, the lower the applied bending stress amplitude is. In Fig. 7, for heat treated (Fig. 7, left) and for additionally shot peened (Fig. 7, right) specimens, S/N-curves in laboratory atmosphere and under corrosive conditions are compared. One can see that in both cases, the corrosive environment has a detrimental effect. However, an important point to be noted is, that in case of heat treated specimens, both S/N-curves are parallel whereas for shot peened specimens, the effect of the corrosive environment is the less pronounced, the lower the stress amplitude was. For bending stress amplitudes of 140 MPa, leading to numbers of cycles to failure of approximately 10^6 the detrimental effect of corrosion is completely cancelled and no difference between tests in laboratory air and in corrosive environment can be observed. To understand this observation, it is necessary to study the stability of residual stresses, introduced in near surface layers by the shot peening process [2]. Typical observations are summarized in Fig. 8. Specimens with approximately identical surface residual stresses were chosen and tested.

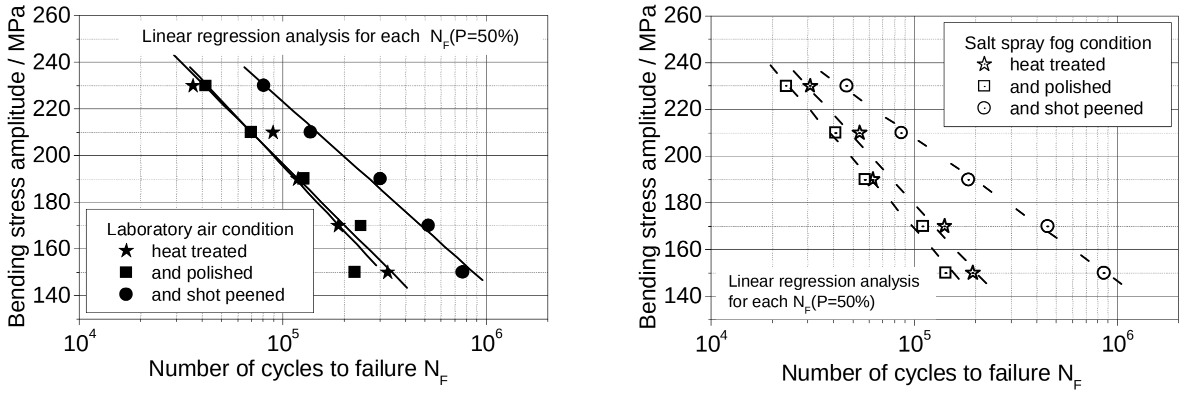

Figure 6: Fatigue endurance limit under ambient conditions (left) and under salt spray conditions (right)

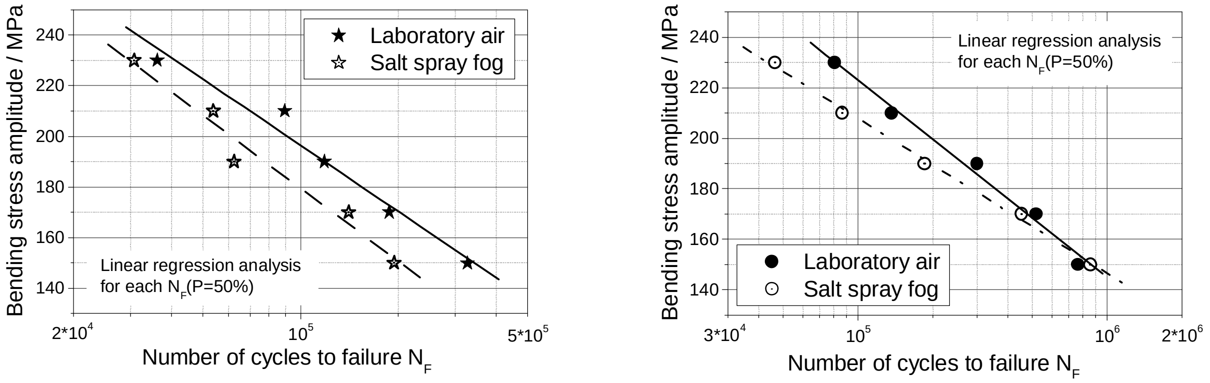

Figure 7: Comparison of heat treated (left) and shot peened (right) specimen under different conditions

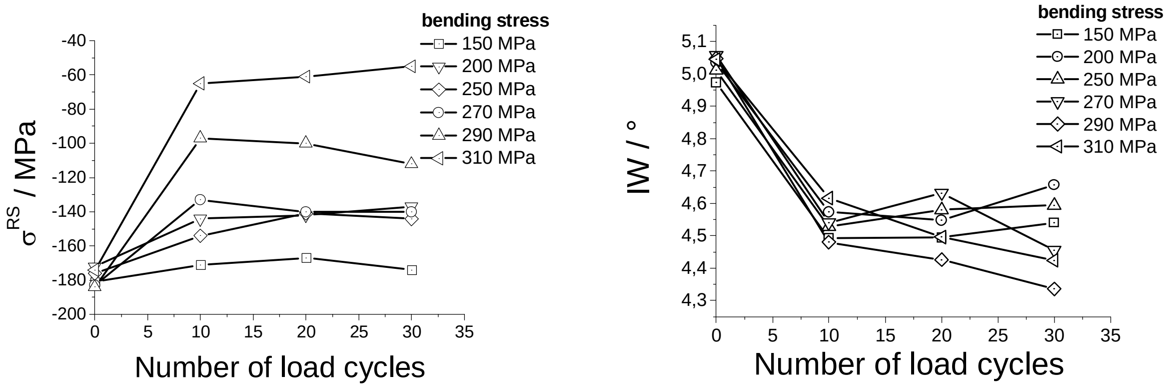

Figure 8: Relaxation of residual stress (left) and integral width (right) of shot peened specimens

During the first loading cycles, residual stress relaxation is the more expressed, the higher the stress amplitude applied is. During further loading, only small changes of the residual stress state occur. This was additionally proved by tests at higher numbers of loading cycles. The same is valid for the IW-values, shown in the right part of Fig. 7. It is important to note, that for a stress amplitude of 150 MPa, residual stresses and strain hardening effects remain almost stable and, hence, are effective to retard crack formation and propagation.

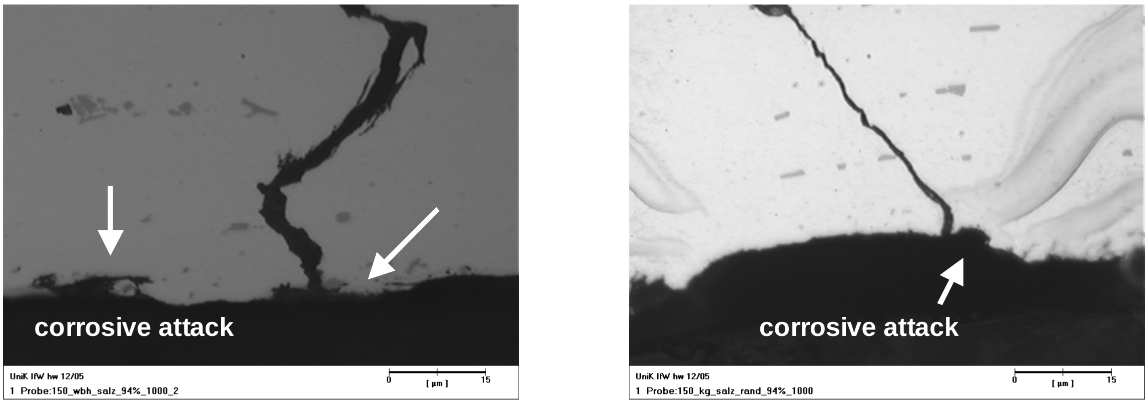

Figure 9: Crack starting from corrosion pittings at untreated (left) and shot peened (right) surface under salt spray fog

Obviously, in this case, the positive effects of compressive residual stress prevail the negative consequences of corrosion, which are the more significant, the longer the test duration is and notch effects due to corrosion pits are completely eliminated. Crack formation was studied, using specimens fatigued to given numbers of cycles, which were then metallographically investigated. Two typical examples are shown in Fig. 9. In all cases, cracks started at corrosion pits. Plastic deformation modifies electrochemical potential and affects thereby rate and activity of corrosion. As a consequence for shot peened specimens, the formation of corrosion pits was more localized in shape of semicircular pits whereas, for rolled ones the corrosion attacks were rather shallow.

CONCLUSIONS

Shot peening is beneficial under laboratory atmosphere as well as under salt spray conditions. Compressive residual stresses are the more beneficial, the lower the bending stress amplitude is. Electrolytical polishing may cause preliminary damage because small pits and therefore local elements are formed.

ACKNOWLEDGMENTS

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